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Sodhi

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[54] **ELECTRONIC BALLAST WITH INVERTER PROTECTION CIRCUIT**

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[73] Assignee: **Motorola Inc.**, Schaumburg, Ill.

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[51] **Int. Cl.**[6] **H05B 37/02**

[52] **U.S. Cl.** **315/225**; 315/127; 315/307

[58] **Field of Search** ..... 315/225, 224, 315/127, 307, DIG. 5, 291, 209 R

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Assistant Examiner—David H. Vu
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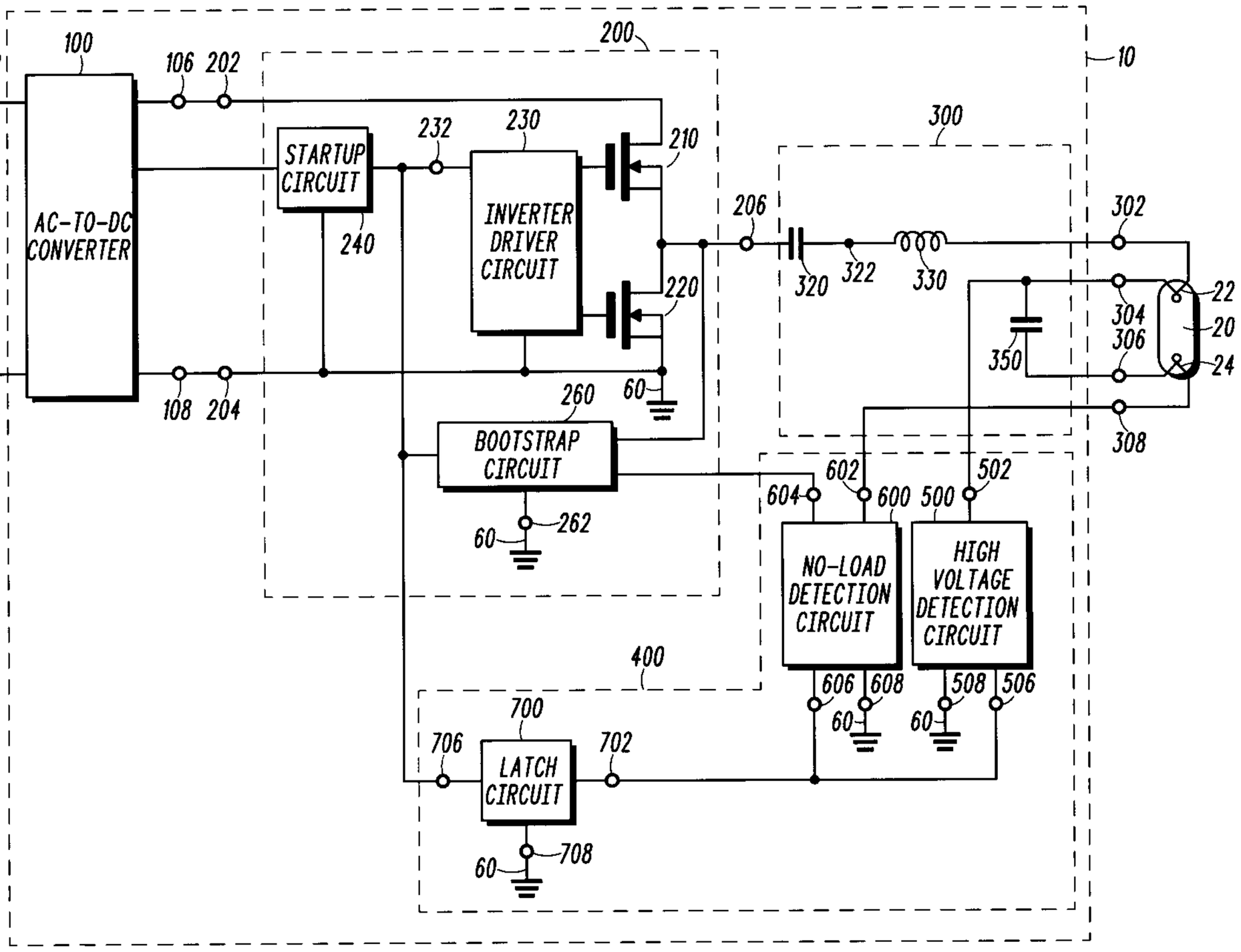
[57] **ABSTRACT**

An electronic ballast (**10**) for powering at least one gas discharge lamp (**20**) comprising an AC-to-DC converter (**100**), an inverter (**200**), an output circuit (**300**), and an inverter protection circuit (**400**). Inverter protection circuit (**400**) includes a high voltage detection circuit (**500**), a no-load detection circuit (**600**), and a latch circuit (**700**), and is operable to turn off the inverter (**200**) in response to removal or failure of the gas discharge lamps. Inverter protection circuit (**400**) is well-suited for use in ballasts that power multiple, parallel-connected lamps and maintains operation of inverter (**200**) under a partially-loaded condition in which at least one operational lamp is present and each of the failed lamps has at least one open filament.

21 Claims, 4 Drawing Sheets



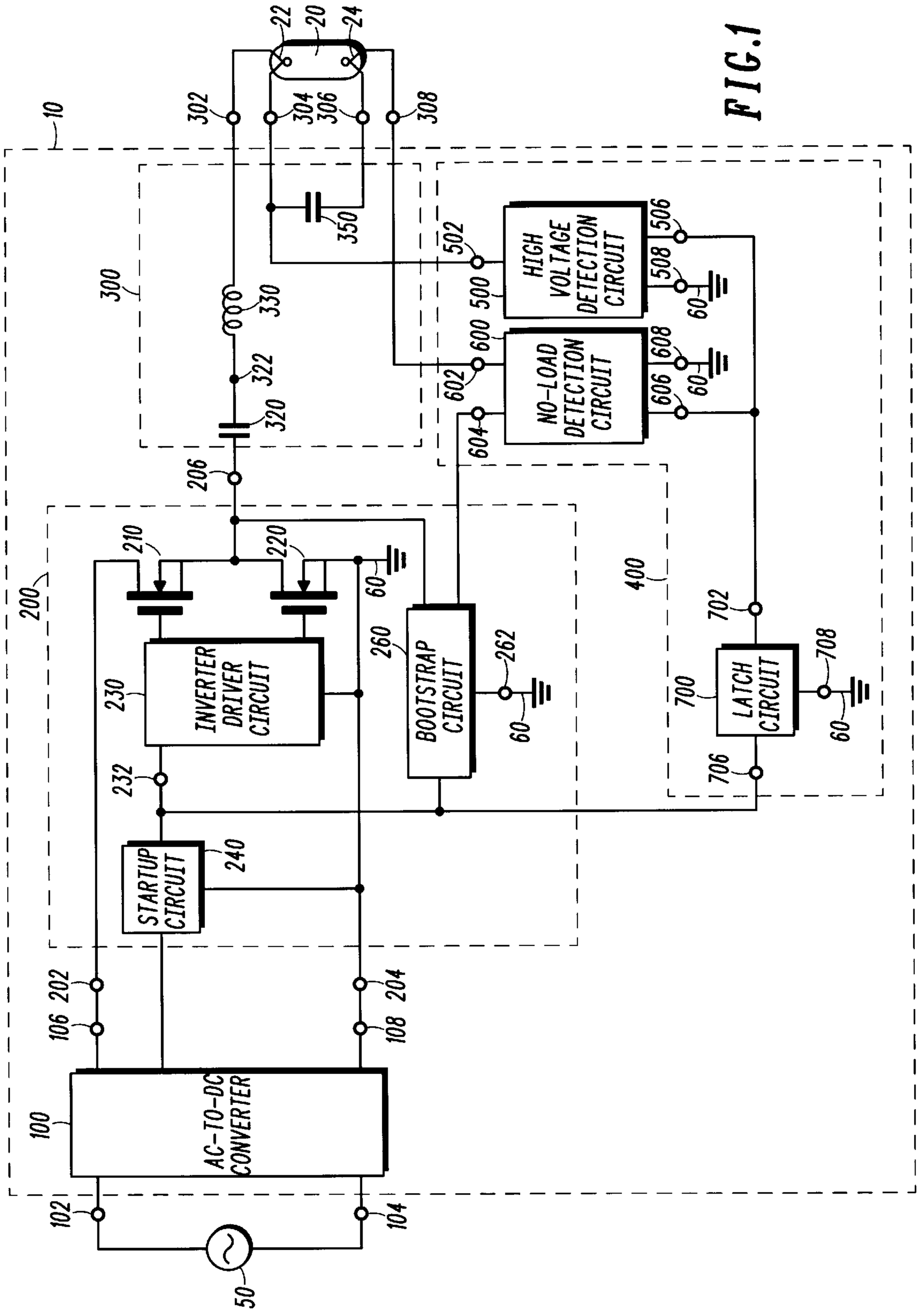
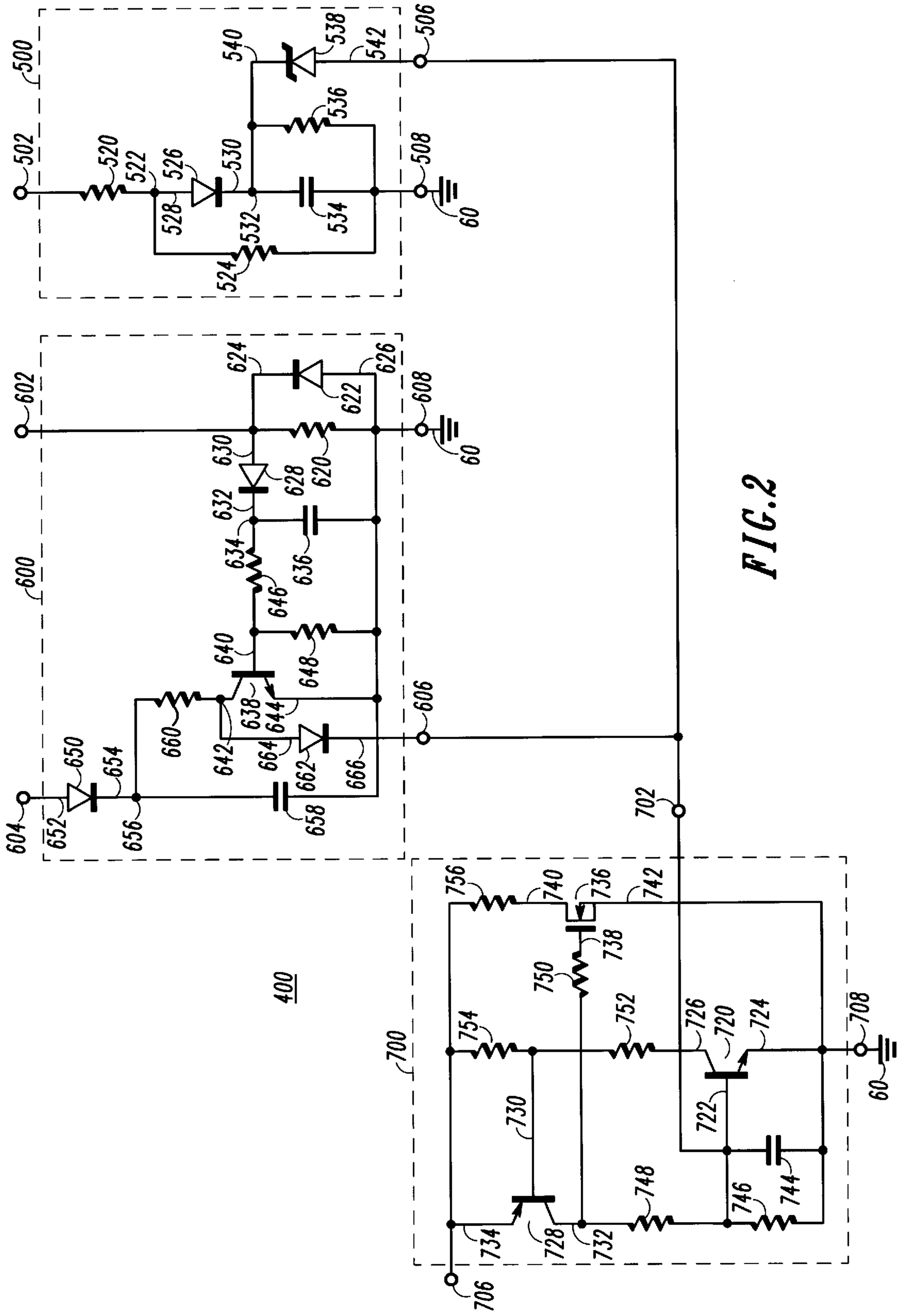

10
22
20
24
302
304
306
308
350
300
330
322
320
206
210
220
60
200
INVERTER DRIVER CIRCUIT
230
232
STARTUP CIRCUIT
240
260
BOOTSTRAP CIRCUIT
262
502
500
HIGH VOLTAGE DETECTION CIRCUIT
506
508
600
602
604
NO-LOAD DETECTION CIRCUIT
608
606
400
702
700
LATCH CIRCUIT
706
708
106
202
108
204
100
AC-TO-DC CONVERTER
102
104
50

FIG.1


500
502
520
522
526
528
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536
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506
508
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600
602
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626
622
608
630
628
620
632
634
636
646
640
648
638
644
606
642
664
662
666
660
650
654
652
656
658
604
400
700
702
756
740
736
742
738
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720
724
708
730
722
748
746
744
734
728
732
706

FIG.2

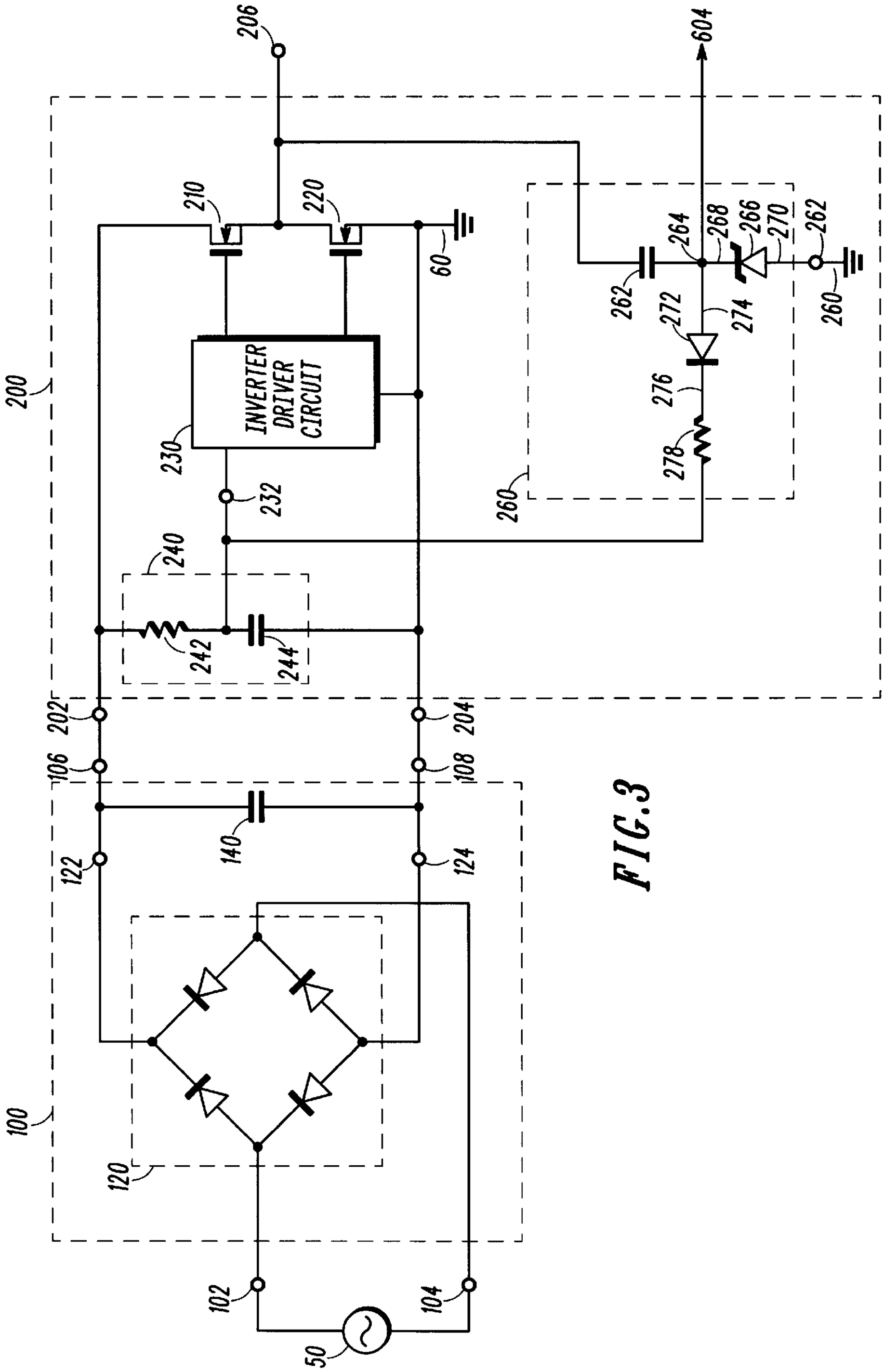
206
604
210
220
60
INVERTER DRIVER CIRCUIT
230
232
240
242
244
200
262
264
268
266
270
262
272
274
260
276
278
260
202
204
106
108
140
122
124
100
120
102
104
50

FIG.3

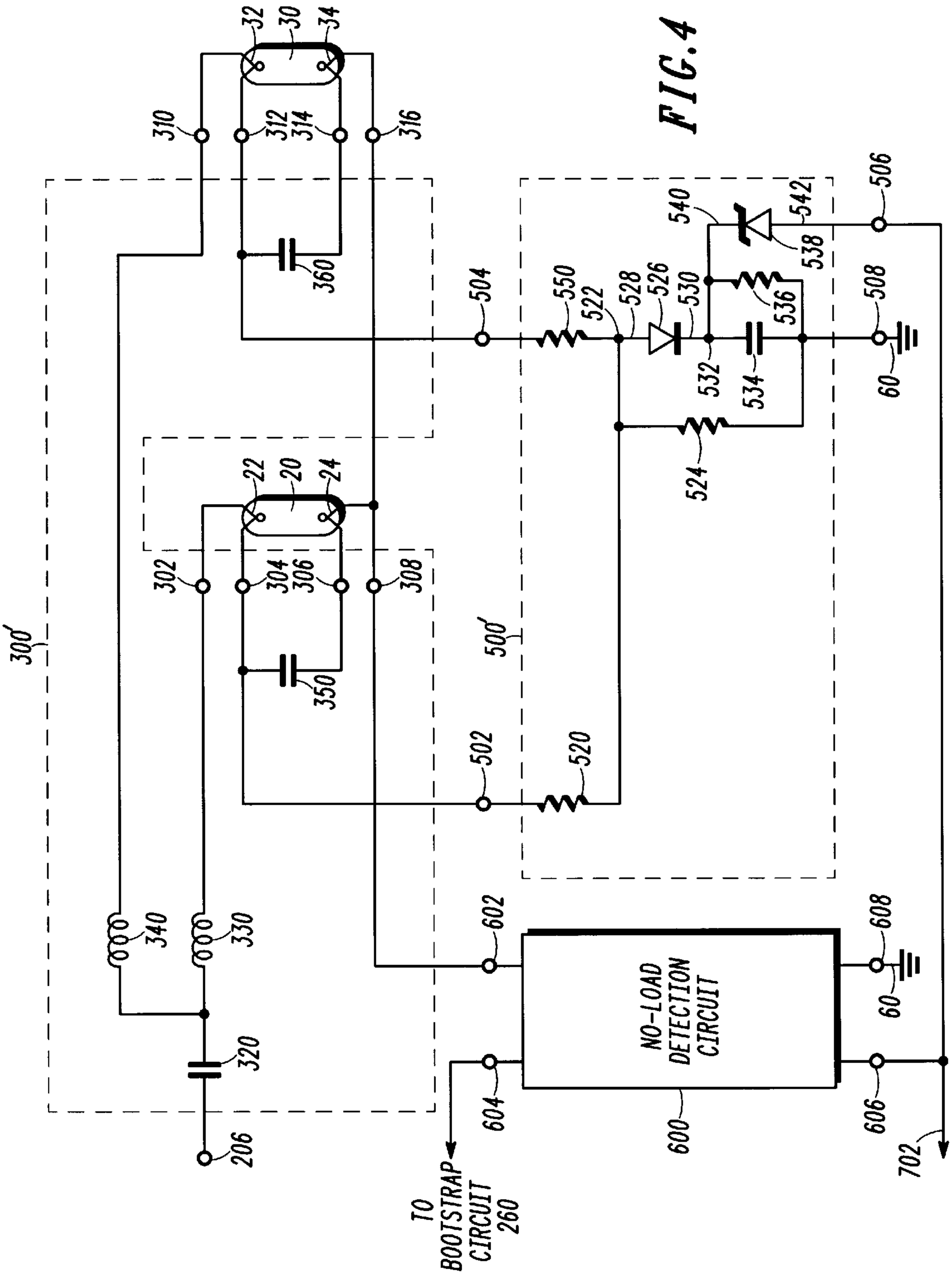
300'
302
304
306
308
310
312
314
316
320
330
340
350
360
20
22
24
30
32
34
500'
502
504
506
508
520
522
524
526
528
530
532
534
536
538
540
542
550
60
600
602
604
606
608
702
206
NO-LOAD DETECTION CIRCUIT
TO BOOTSTRAP CIRCUIT 260

FIG. 4

ELECTRONIC BALLAST WITH INVERTER PROTECTION CIRCUIT

FIELD OF THE INVENTION

The present invention relates to the general subject of circuits for powering gas discharge lamps and, in particular, to an electronic ballast with an inverter protection circuit.

BACKGROUND OF THE INVENTION

Electronic ballasts typically include an inverter that provides high frequency current for efficiently powering gas discharge lamps. Inverters are generally classified according to their topology (e.g., half-bridge or push-pull) and the method used to control commutation of the inverter switches (e.g., driven or self-oscillating). In many types of electronic ballasts, the inverter is a driven half-bridge in which two alternately conducting power transistors are used to provide a square wave output voltage. The square wave output voltage of the inverter is processed by a resonant output circuit that provides high voltage for igniting the lamps, as well as a magnitude-limited current for powering the lamps.

When the lamps fail, are removed, or otherwise cease to operate in a normal fashion, it is highly desirable that the inverter be shut down or shifted to a different mode of operation. This is necessary in order to minimize power dissipation, reduce heating in the ballast, and protect the inverter transistors from damage due to excessive voltage, current, and heat. Circuits that shut down or alter the operation of the inverter in response to lamp removal or failure are customarily referred to as inverter protection circuits.

One known type of inverter protection circuit monitors the resonant output circuit for overvoltage and correspondingly turns the inverter driver circuit off if the voltage exceeds a certain level. This approach is not attractive for those ballasts in which the lamps are "direct coupled" in series with the resonant circuit, since removal or failure of the lamps actually opens the resonant circuit and thereby prevents the development of high voltage in the resonant circuit. However, even with the resonant circuit open, the inverter continues to operate, resulting in unnecessary power dissipation in the inverter switches.

Another known approach utilizes a current path through the lamp filaments to detect lamp removal or failure. This approach alone is inadequate for those situations in which a lamp fails to operate in a normal manner, but its filaments remain intact, such as what occurs with "degassed" and "diode mode" lamps. Furthermore, if multiple lamps are present, and if a single current path through the filaments of all the lamps is used, the inverter is shut down even if only one filament of one lamp fails but the remaining lamps are operational and with their filaments intact. This is unnecessary and undesirable, since it is preferred to have the inverter continue to operate so that the remaining operational lamps may continue to provide illumination, thus obviating any urgent need for replacement of the single failed lamp.

It is therefore apparent that a need exists for an inverter protection circuit for a driven half-bridge type inverter that provides protection of the inverter switches and other ballast components under various lamp failure modes, such as lamp removal or a degassed lamp, but that allows the inverter to continue to operate when at least one operational lamp is present and when the failed lamps present no danger to the inverter. Such a circuit would represent a considerable advance over the prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a bock diagram of an electronic ballast with an inverter protection circuit, in accordance with the present invention.

FIG. **2** is schematic diagram of an inverter protection circuit, in accordance with a preferred embodiment of the present invention.

FIG. **3** is a schematic diagram of an AC-to-DC converter and an inverter, in accordance with a preferred embodiment of the present invention.

FIG. **4** is schematic diagram of an output circuit and a high voltage detection circuit for use in an electronic ballast for powering two gas discharge lamps, in accordance with a second preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An electronic ballast **10** for powering at least one gas discharge lamp **20** is described in FIG. **1**. Ballast **10** comprises an alternating current (AC) to direct current (DC) converter **100**, an inverter **200**, an output circuit **300**, and an inverter protection circuit **400**. Ballast **10** also includes a set of output wires **302**, . . . ,**308** adapted to being coupled to gas discharge lamp **20**. Specifically, first output wire **302** is coupleable to second output wire **304** through a first filament **22** of lamp **20**, and third output wire **306** is coupleable to fourth output wire **308** through a second filament **24** of lamp **20**.

AC-to-DC converter **100** includes a pair of input connections **102,104** for receiving a source of alternating current **50**, and a pair of output connections **106,108**. Inverter **200** comprises first and second input terminals **202,204**, an output terminal **206**, a first inverter switch **210**, a second inverter switch **220**, an inverter driver circuit **230**, a startup circuit **240**, and a bootstrap circuit **260**. First and second input terminals **202,204** are coupled to the output connections **106,108** of AC-to-DC converter **100**. Second input terminal **204** is also coupled to a circuit ground node **60**. First inverter switch **210** is coupled between first input terminal **202** and output terminal **206**, while second inverter switch **220** is coupled between output terminal **206** and circuit ground node **60**. First and second inverter switches **210,220** may be implemented using any of a number of controllable power switches, such as field-effect transistors (shown in FIG. **1**) or bipolar junction transistors.

Inverter driver circuit **230** is coupled to, and operable to complementarily commutate, first and second inverter switches **210,220**. That is, inverter driver circuit **230** controls conduction of inverter switches **210,220** so that when first switch **210** is on, second switch **220** is off, and vice versa. Inverter driver circuit **230**, which may be implemented using a discrete circuit or an integrated circuit (IC) such as the IR2151 high-side driver IC manufactured by International Rectifier, includes a DC supply input **232** for receiving operating power. Startup circuit **240**, coupled between AC-to-DC converter **100** and DC supply input **232**, is operable to provide power for initiating operation of inverter driver circuit **230**. Bootstrap circuit **260** is coupled between output terminal **206** and DC supply input **232** of inverter driver circuit **230**, and includes a ground connection **262** coupled to circuit ground node **60**. During operation, bootstrap circuit **260** provides steady-state operating power to inverter driver circuit **230**.

Output circuit **300** comprises a direct current (DC) blocking capacitor **320**, a resonant inductor **330**, and a resonant capacitor **350**. DC blocking capacitor **320** is coupled between inverter output terminal **206** and a first junction **322**. Resonant inductor **330** is coupled between first junction **322** and first output wire **302**. Resonant capacitor **350** is coupled between second output wire **304** and third output

wire **306**. Output circuit **300** is configured as a series resonant circuit that provides a high voltage for igniting lamp **20** and a magnitude-limited current for steady-state powering of lamp **20**. Additionally, output circuit **300** is often referred to as a direct-coupled arrangement, in that physical disconnection of lamp **20** from output wires **302**, . . . , **308**, or failure of either of the lamp filaments **22**,**24**, effectively disconnects resonant capacitor **350** from the rest of output circuit **300**. Thus, output circuit **300** provides the advantage of automatically shutting off the resonant circuit, and therefore preventing an otherwise high voltage from developing across resonant capacitor **350**, in response to removal of, or open filaments in, lamp **20**.

Despite the fact that output circuit **300** will shut off when lamp **20** is removed or when either one or both of filaments **22**,**24** become open, inverter driver circuit **230** will, in the absence of additional protection measures, continue to operate and provide switching of inverter switches **210**,**220**. Consequently, inverter switches **210**,**220** will needlessly dissipate a considerable amount of power. Hence the need for a protection circuit to reduce or eliminate unnecessary power dissipation in the inverter switches when lamp **20** is removed or failed.

The need for a protection circuit becomes considerably more urgent if lamp **20** is, or at some point at the end of its operating life becomes, a "degassed" or "diode mode" lamp. In this case, output circuit **300** will not automatically shut off since filaments **22**,**24** will remain intact for at least a short period of time, thus keeping resonant capacitor **350** connected to the rest of output circuit **300**. With lamp **20** degassed, for example, the voltages across resonant inductor **330** and resonant capacitor **350** will become extremely high since little or no loading is presented by the degassed lamp. The result is exposure of inverter switches **210**,**220** and output circuit **300** to potentially destructive levels of voltage, current, and power dissipation. In order to prevent such a situation, a protection circuit is needed that shuts down, or at least significantly alters the operation of, inverter driver circuit **230** in response to lamp **20** failing to conduct current in a substantially normal manner.

As described in FIG. **1**, protection circuit **400** comprises a high voltage detection circuit **500**, a no-load detection circuit **600**, and a latch circuit **700**. High voltage detection circuit includes a high voltage detect input **502** coupled to second output wire **304**, a ground connection **508** coupled to circuit ground node **60**, and a high voltage detect output **506**. No-load detection circuit includes a no-load detect input **602** coupled to fourth output wire **308**, a bootstrap detect input **604** coupled to bootstrap circuit **260**, a no-load detect output **606** coupled to high voltage detect output **506**, and a ground connection **608** coupled to circuit ground **60**. Latch circuit **700** includes a latch input **702** coupled to no-load detect output **606**, a latch output **706** coupled to the DC supply input **232** of inverter driver circuit **230**, and a ground connection **708** coupled to circuit ground node **60**.

Inverter protection circuit **400** is operable, in response to removal or failure of lamp **20**, to turn off inverter driver circuit **230** by coupling the DC supply input **232** of inverter driver circuit **230** to circuit ground node **60**. With DC supply input **232** coupled to circuit ground node **60**, inverter driver circuit **230** is deprived of operating power and turns off. Thus, inverter protection circuit **400** supplements the insufficient degree of protection afforded by output circuit **300** by shutting down inverter **200** in when lamp **20** fails or is removed.

In a preferred embodiment of electronic ballast **10**, inverter protection circuit **400** is operable to inactivate inverter driver circuit **230** by coupling DC supply input **232** to circuit ground node **60** in response to one or both of the following conditions: (1) the voltage at the high voltage detect input **502** being greater than a predetermined over-voltage threshold, V_{HIGH}; and (2) the current flowing into the no-load detect input being less than a predetermined no-load threshold, I_{LOW}. Referring to FIG. **1**, the first condition occurs when lamp **20** is degassed or in diode mode, or when lamp **20** otherwise fails to conduct current in a substantially normal manner. The second condition occurs when lamp **20** is removed or when one or both of filaments **22**,**24** are open.

Turning now to FIG. **2**, in a preferred embodiment of inverter protection circuit **400**, high voltage detection circuit **500** comprises a first resistor **520**, a second resistor **524**, a diode **526**, a capacitor **534**, a third resistor **536**, and a zener diode **538**. First resistor **520** is coupled between high voltage detect input **502** and a first node **522**. Second resistor **524** is coupled between first node **522** and circuit ground node **60**. Diode **526** has an anode **528** coupled to first node **522** and a cathode **530** coupled to a second node **532**. Capacitor **534** and third resistor **536** are each coupled between second node **532** and circuit ground node **60**. Zener diode **538** has a cathode **540** coupled to second node **532** and an anode **542** coupled to high voltage detect output **506**.

During operation, high voltage detect circuit **500** monitors the voltage, V_{OUT}, at the second output wire **304** and provides an output voltage at high voltage detect output **506** if V_{OUT} exceeds V_{HIGH}. Conversely, as long as V_{OUT} is less than V_{HIGH}, no voltage is provided at output **506**. First resistor **520** and second resistor **524** function as a voltage divider circuit for transferring a fractional portion of V_{OUT} into capacitor **534** via first diode **526**. Diode **526** serves as a rectifier that allows capacitor **534** to charge up during the positive half cycles of V_{OUT} and prevents capacitor **534** from discharging during the negative half cycles of V_{OUT}. Zener diode **538** acts as a threshold trigger that turns on (i.e., reverse conducts) and delivers current to high voltage detect output **506** if the voltage across capacitor **534** attempts to exceed the zener voltage, V_Z, of zener diode **538**. The resistances of divider resistors **520**,**524** are selected so that V_{OUT} exceeding V_{HIGH} correspondingly causes the voltage across capacitor **534** to attempt to exceed V_Z. Resistors **520**,**524** and capacitor **534** also provide a useful RC time delay that prevents high voltage detection circuit **500** from providing an output voltage that effects engagement of latch circuit **700** until some time after lamp **20** has first been given a reasonable period of time in which to ignite. Resistor **536** serves as a reset resistor for discharging capacitor **534** when AC power is removed from the ballast so that, upon reapplication of AC power, high voltage detection circuit **500** provides a reasonably consistent delay period to allow for ignition of lamp **20**.

Referring again to FIG. **2**, in a preferred embodiment of inverter protection circuit **400**, no-load detection circuit comprises a first resistor **620**, a first diode **622**, a second diode **628**, a first capacitor **636**, an electronic switch **638**, a second resistor **646**, a third resistor **648**, a third diode **650**, a second capacitor **658**, a fourth resistor **660**, and a fourth diode **662**. First resistor **620** is coupled between no-load detect input **602** and circuit ground node **60**. First diode **622** has a cathode **624** coupled to no-load detect input **602** and an anode **626** coupled to circuit ground node **60**. Second diode **628** has an anode **630** coupled to no-load detect input **602** and a cathode **632** coupled to a first node **634**. First capacitor **636** is coupled between first node **634** and circuit ground node **60**. Electronic switch **638** is preferably imple-

mented using a NPN-type bipolar junction transistor (BJT) having a base lead **640**, a collector lead **642**, and an emitter lead **644**. Emitter lead **644** is coupled to circuit ground node **60**. Second resistor **646** is coupled between first node **634** and base lead **640**. Third resistor **648** is coupled between base lead **640** and circuit ground node **60**. Third diode **650** has an anode **652** coupled to bootstrap detect input **604** and a cathode **654** coupled to a second node **656**. Second capacitor **658** is coupled between second node **656** and circuit ground node **60**. Fourth resistor **660**, which serves as a current limiting resistor for transistor **638**, is coupled between second node **656** and collector lead **642**. Fourth diode **662** has an anode **664** coupled to collector lead **642** and a cathode **666** coupled to no-load detect output **606**.

Referring back to FIG. **1**, the current that flows out of third output wire **306**, through second filament **24**, and back into fourth output wire **308** is herein referred to as the "return current." During operation of ballast **10**, no-load detection circuit **600** monitors the return current, which flows into no-load detect input **602**, as an indicator of whether or not a lamp with both filaments intact is indeed connected to the ballast. Returning now to FIG. **2**, a portion of the positive-going half cycles of the return current flows to circuit ground through resistor **620**, thus providing a voltage across resistor **620** that is proportional to the magnitude of the return current. The negative-going half cycles flow up from circuit ground node **60** through diode **622**, which serves as a bypass diode for reducing the amount of power dissipated in resistor **620**.

If a return current is present, indicating that at least one lamp with intact filaments is connected to the ballast, capacitor **636** will charge up during the positive-going half-cycles of the return current. Resistors **646**,**648** scale down the voltage across capacitor **636** for application to the base lead **640** of transistor **638**. Once the voltage across resistor **648** becomes sufficiently high, transistor **638** turns on and remains on as long as a return current is present. With transistor **638** on, diode **662** is reverse-biased since its anode **664** is effectively coupled to near ground potential through transistor **638**. Consequently, no-load detect output is prevented from developing a voltage sufficient to effect engagement of latch circuit **700**. If, on the other hand, no return current is present, transistor **638** does not turn on. With transistor **638** off, the voltage at bootstrap detect input **604**, which develops shortly after inverter switching commences, is substantially transferred to no-load detect output **606**. Consequently, latch circuit **700** becomes engaged and inactivates inverter driver circuit **230**.

Referring again to FIG. **2**, latch circuit **700** comprises a first electronic switch **720**, a second electronic switch **728**, a third electronic switch **736**, a first capacitor **744**, a first resistor **746**, a second resistor **748**, a third resistor **750**, a fourth resistor **752**, a fifth resistor **754**, and a sixth resistor **756**. First electronic switch **720** preferably comprises a NPN-type BJT having a base lead **722** coupled to latch input **702**, an emitter lead **724** coupled to circuit ground node **60**, and a collector lead **726**. Second electronic switch **728** preferably comprises a PNP-type BJT having a base lead **730**, a collector lead **732**, and an emitter lead **734**. Emitter lead **734** is coupled to latch output **706**. Third electronic switch **736** preferably comprises a N-channel field effect transistor (FET) having a gate lead **738**, a drain lead **740**, and a source lead **742**. Source lead **742** is coupled to circuit ground node **60**. For improved operation of latch circuit **700**, it is further preferred that transistor **736** be implemented using an insulated gate enhancement-mode FET, such as the 2N7002 manufactured by Motorola, Inc., that is capable of turning on, and remaining on, for relatively low values of gate-to-source voltage (e.g., on the order of about 2 volts) and drain-to-source voltage. First capacitor **744** and first resistor **746** are each coupled between latch input **702** and circuit ground node **60**. Second resistor **748** is coupled between latch input **702** and the collector lead **732** of transistor **728**. Third resistor **750** is coupled between collector lead **732** and the gate lead **738** of transistor **736**. Fourth resistor **752** is coupled between the collector lead **726** of transistor **720** and the base lead **730** of transistor **728**. Fifth resistor **754** is coupled between latch output **706** and base lead **730**. Finally, sixth resistor **756** is coupled between latch output **706** and the drain lead **740** of transistor **736**.

The operation of latch circuit **700** is now explained with reference to FIGS. **1** and **2** as follows. In response to a lamp fault condition, high voltage protection circuit **500** and/or no-load detection circuit **60**, provide a voltage, Vlatch, at latch input **702** that is sufficient (i.e., at least **0.7** volts or so) to cause transistor **720** to turn on. When inverter **200** is operating, latch output **706** has a voltage, V_{DC}, on the order of around **15** volts that, once transistor **720** turns on, is distributed between resistors **752**,**754**. Consequently, transistor **728** becomes forward-biased and turns on. With transistor **728** on, the voltage at collector lead **732** becomes high enough to turn on transistor **736**. Once transistor **736** turns on, latch output **706** is then coupled, by way of resistor **756**, to circuit ground node **60**, thus effectively shunting DC supply input **232** to ground and turning off inverter driver circuit **230**. Once inverter driver circuit **230** turns off, transistor **736** will remain on (due to current provided by startup circuit **240**) and actively prevent the voltage at DC supply input **232** from building up and reaching a level sufficient to initiate operation of inverter driver circuit **230**. That is, latch circuit **700** remains on until at least such time as AC power is removed from ballast **10**. Once engaged, latch circuit **700** disengages only after AC power is removed from ballast **10**.

Turning now to FIG. **3**, AC-to-DC converter **100** preferably includes a rectifier circuit **120** that is operable to accept the source of alternating current **50** and to provide a rectified voltage between a pair of rectifier circuit output terminals **122**,**124**. AC-to-DC converter **100** may also include a filtering capacitor **140** for reducing the amount of AC ripple present in the output voltage provided by rectifier circuit **100**. AC-to-DC converter **100** may also include a boost converter (not shown), inserted between output terminals **122**,**124** and output connections **106**,**108**, for providing power factor correction and line regulation.

Preferred implementations for startup circuit **240** and bootstrap circuit **260** are also illustrated in FIG. **3**. Startup circuit **240** preferably comprises a resistor **242** coupled between DC supply input **232** and output terminal **122** of rectifier circuit **120**, and a capacitor **244**. Bootstrap circuit **260** comprises a capacitor **262**, a zener diode **266**, a diode **272**, and a resistor **278**. Capacitor **262** serves as an AC coupling capacitor for extracting a limited amount of current from inverter output terminal **206** and is coupled between the inverter output terminal **206** and a first node **264**. First node **264** is coupled to the bootstrap detect input **604** of no-load detection circuit **600**. Zener diode **266**, which functions as a voltage regulator that safely limits the amount of voltage provided to DC supply input **232**, has a cathode **268** coupled to first node **264** and an anode **270** coupled to circuit ground node **60**. Diode **272**, which serves as a rectifier for transferring only positive-going current to DC supply input **232**, has a cathode **276** and an anode **274** that is coupled to first node **264**. Resistor **278** is a current limiting element and is coupled between DC supply input **232** and cathode **276** of diode **272**.

When AC power is first applied to the ballast, capacitor **244** is initially uncharged, and inverter driver circuit **230** is off and remains off until such time as the voltage, V_{DC}, at DC supply input **232** reaches a certain level. With AC power applied to the ballast, rectifier circuit **120** provides a full-wave rectified voltage across output terminals **122,124**, and capacitor **244** begins to charge up due to current delivered to it via resistor **242**. Once the voltage across capacitor **244** reaches a certain predetermined level (e.g., 8.2 volts), inverter driver circuit **230** turns on and, using the energy stored in capacitor **244**, begins switching of inverter switches **210,220**. At this point, the energy stored in capacitor **244** begins to be depleted. However, with inverter switching now taking place, bootstrap circuit **260** begins to operate and provides the steady-state power needed to keep inverter driver circuit **230** operating. Capacitor **244** additionally serves as a filtering capacitor for storing energy provided by bootstrap circuit **260**. Thus, startup circuit **240** provides a relatively small amount of energy for initially activating inverter driver circuit **230**, while bootstrap circuit **260** supplies steady-state power for sustaining operation of inverter driver circuit **230**.

Appropriate modifications can be made to output circuit **300** and high voltage detection circuit **500** to render ballast **10** suitable for powering more than one gas discharge lamp. In one such embodiment, as illustrated in FIG. **4**, output circuit **300'** additionally includes a second resonant inductor **340**, a second resonant capacitor **360**, and a second set of output wires **310**, . . . ,**316** adapted to being coupled to a second gas discharge lamp **30**. Second resonant inductor **340** is coupled between first junction **322** and a fifth output wire **310**. Second resonant capacitor is coupled between a sixth output wire **312** and a seventh output wire **314**. Fifth output wire **310** is coupleable to sixth output wire **312** through a first filament **32** of lamp **30**, while seventh output wire **314** is coupled to eighth output wire **316** through a second filament **34** of lamp **30**. High voltage detection circuit **500'** additionally includes a second high voltage detect input **504** that is coupled to sixth output wire **312**, as well as a fourth resistor **550** coupled between second high voltage detect input **504** and first node **522**. Fourth resistor **550** is analogous in function to resistor **520** and allows high voltage detection circuit **500'** to monitor for overvoltage due to second lamp **30** becoming degassed or operating in the diode mode. As a result, high voltage detection circuit **500'** is operable to effect engagement of latch circuit **700** if either one of the lamps is degassed or operating in the diode mode with both of its filaments intact.

As shown in FIG. **4**, the combined return current of both lamps **20,30** flows into no-load detect input **602** of no-load detection circuit **600**. Consequently, and recalling the previous discussion with regard to FIG. **2**, both lamps must be removed or each lamp must have at least one open filament in order for no-load detection circuit **600** to effect engagement of latch circuit **700** (and, thus, shutdown of inverter driver circuit **230**). For example, if lamp **20** is removed, while lamp **30** remains and operates normally, a nonzero return current is still provided to no-load detect input **602**, thus preventing no-load detection circuit **600** from engaging latch circuit **700**. Consequently, the inverter will not be shut down since removed lamp **20** presents no danger to continued safe operation of the inverter. On the other hand, if either lamp fails to conduct current in a normal manner, but both of its filaments remain intact (i.e., such as what may occur with a degassed or diode mode lamp), inverter driver circuit **230** will be shut down, regardless of the condition of the other lamp, in order to protect the inverter and output circuit from almost certain damage. In this way, protection circuit **400** provides a high degree of protection for inverter **200** under a number of lamp failure modes, yet accommodates "parallel" operation by which the remaining functional lamp is allowed to continue to operate, and thus provide useful illumination, if the other lamp is either (i) removed; or (ii) failed, with at least one open filament.

Although the present invention has been described with reference to a certain preferred embodiment, numerous modifications and variations can be made by those skilled in the art without departing from the novel spirit and scope of this invention.

What is claimed is:

1. An electronic ballast for powering a gas discharge lamp, comprising:

an AC-to-DC converter having a pair of input connections adapted to receive a source of alternating current, and a pair of output connections;

a set of output wires comprising first, second, third, and fourth output wires adapted to being coupled to a gas discharge lamp, wherein the first output wire is coupleable to the second output wire through a first filament of the lamp, and the third output wire is coupleable to the fourth output wire through a second filament of the lamp;

an inverter, comprising:

first and second input terminals coupled to the output connections of the AC-to-DC converter, the second input terminal being coupled to a circuit ground node;

an output terminal;

a first inverter switch coupled between the first input terminal and the output terminal;

a second inverter switch coupled between the output terminal and the circuit ground node;

an inverter driver circuit coupled to, and operable to complementarily commutate, the first and second inverter switches, the inverter driver circuit including a DC supply input for receiving operating power for the inverter driver circuit;

a startup circuit coupled between the AC-to-DC converter and the DC supply input of the inverter driver circuit, the startup circuit being operable to provide power for initiating operation of the inverter driver circuit; and

a bootstrap circuit coupled between the inverter output terminal and the DC supply input of the inverter driver circuit, the bootstrap circuit having a ground connection coupled to the circuit ground node and being operable to provide steady-state operating power to the inverter driver circuit;

an output circuit comprising:

a DC blocking capacitor coupled between the inverter output terminal and a first junction;

a resonant inductor coupled between the first junction and the first output wire; and

a resonant capacitor coupled between the second and third output wires; and

an inverter protection circuit operable, in response to removal or failure of the lamp, to turn off the inverter driver circuit by coupling the DC supply input of the inverter driver circuit to the circuit ground node, the inverter protection circuit comprising:

a high voltage detection circuit having a high voltage detect input coupled to the second output wire, a ground connection coupled to the circuit ground node, and a high voltage detect output;

a no-load detection circuit having a no-load detect input coupled to the fourth output wire, a bootstrap detect input coupled to the bootstrap circuit, a no-load detect output coupled to the high voltage detect output, and a ground connection coupled to the circuit ground node; and

a latch circuit having a latch input coupled to the no-load detect output, a latch output coupled to the DC supply input of the inverter driver circuit, and a ground connection coupled to the circuit ground node.

2. The electronic ballast of claim **1**, wherein the inverter protection circuit is operable to inactivate the inverter driver circuit by coupling the DC supply input to the circuit ground node in response to at least one of:

(i) the voltage at the high voltage detect input being greater than a predetermined overvoltage threshold; and

(ii) the current flowing into the no-load detect input being less than a predetermined no-load threshold.

3. The electronic ballast of claim **2**, wherein the voltage at the high voltage detect input exceeds the predetermined overvoltage threshold in response to:

(i) both lamp filaments being intact; and

(ii) failure of the lamp to conduct current in a substantially normal fashion.

4. The electronic ballast of claim **2**, wherein the current flowing into the no-load detect input falls below a predetermined no-load threshold in response to at least one of:

(i) removal of the lamp; and

(ii) failure of at least one filament of the lamp.

5. The electronic ballast of claim **1**, wherein the first and second inverter switches each comprise at least one of a bipolar junction transistor and a field effect transistor.

6. The electronic ballast of claim **1**, wherein the high voltage detection circuit comprises:

a first resistor coupled between the high voltage detect input and a first node;

a second resistor coupled between the first node and the circuit ground node;

a diode having an anode coupled to the first node and a cathode coupled to a second node;

a capacitor coupled between the second node and the circuit ground node;

a third resistor coupled between the second node and the circuit ground node; and

a zener diode having a cathode coupled to the second node and an anode coupled to the high voltage detect output.

7. The electronic ballast of claim **1**, wherein the no-load detection circuit comprises:

a first resistor coupled between the no-load detect input and the circuit ground node;

a first diode having a cathode coupled to the no-load detect input and an anode coupled to the circuit around node;

a second diode having an anode coupled to the no-load detect input and a cathode coupled to a first node;

a first capacitor coupled between the first node and the circuit ground node;

an electronic switch having a base lead, a collector lead, and an emitter lead, the emitter lead being coupled to the circuit ground node;

a second resistor coupled between the first node and the base lead of the electronic switch;

a third resistor coupled between the base lead of the electronic switch and the circuit ground node;

a third diode having an anode coupled to the bootstrap detect input and a cathode coupled to a second node;

a second capacitor coupled between the second node and the circuit ground node;

a fourth resistor coupled between the second node and the collector lead of the electronic switch; and

a fourth diode having an anode coupled to the collector lead of the electronic switch and a cathode coupled to the no-load detect output.

8. The electronic ballast of claim **7**, wherein the electronic switch comprises a NPN-type bipolar junction transistor.

9. The electronic ballast of claim **1**, wherein the latch circuit comprises:

a first electronic switch having a base lead coupled to the latch input, an emitter lead coupled to the circuit ground node, and a collector lead;

a second electronic switch having a base lead, a collector lead, and an emitter lead, the emitter lead being coupled to the latch output;

a third electronic switch having a gate lead, a drain lead, and a source lead, the source lead being coupled to the circuit ground node;

a capacitor coupled between the latch input and the circuit ground node;

a first resistor coupled between the latch input and the circuit ground node;

a second resistor coupled between the latch input and the collector lead of the second electronic switch;

a third resistor coupled between the collector lead of the second electronic switch and the gate lead of the third electronic switch;

a fourth resistor coupled between the collector lead of the first electronic switch and the base lead of the second electronic switch;

a fifth resistor coupled between the latch output and the base lead of the second electronic switch; and

a sixth resistor coupled between the latch output and the drain lead of the third electronic switch.

10. The electronic ballast of claim **9**, wherein the first electronic switch comprises a NPN-type bipolar junction transistor, the second electronic switch comprises a PNP-type bipolar junction transistor, and the third electronic switch comprises a N-channel field effect transistor.

11. The electronic ballast of claim **1**, wherein the bootstrap circuit comprises:

a capacitor coupled between the inverter output terminal and a first node, the first node being coupled to the bootstrap detect input of the no-load detection circuit;

a zener diode having a cathode coupled to the first node and an anode coupled to the circuit ground node;

a diode having an anode and a cathode, the anode being coupled to the first node; and

a resistor coupled between the cathode of the diode and the DC supply input of the inverter driver circuit.

12. The electronic ballast of claim **1**, wherein the AC-to-DC converter further comprises a rectifier circuit operable to accept the source of alternating current and to provide a rectified voltage between a pair of rectifier circuit output terminals.

13. The electronic ballast of claim **12**, wherein the startup circuit comprises:

a resistor coupled between the DC supply input of the inverter driver circuit and one of the output terminals of the rectifier circuit; and

a capacitor coupled between the DC supply input and the circuit ground node.

14. An electronic ballast for powering at least two gas discharge lamps, comprising:

an AC-to-DC converter having a pair of input connections adapted to receive a source of alternating current, and a pair of output connections;

a first set of output wires comprising first, second, third, and fourth output wires adapted to being coupled to a first gas discharge lamp, wherein:

the first output wire is coupleable to the second output wire through a first filament of the first lamp; and

the third output wire is coupleable to the fourth output wire through a second filament of the first lamp;

a second set of output wires comprising fifth, sixth, seventh, and eighth output wires adapted to being coupled to a second gas discharge lamp, wherein:

the fifth output wire is coupleable to the sixth output wire through a first filament of the second lamp; and

the seventh output wire is coupleable to the eighth output wire through a second filament of the second lamp, the eight output wire being coupled to the fourth output wire;

an inverter, comprising:

first and second input terminals coupled to the output connections of the AC-to-DC converter, the second input terminal being coupled to a circuit ground node;

an output terminal;

a first inverter switch coupled between the first input terminal and the output terminal;

a second inverter switch coupled between the output terminal and the circuit ground node;

an inverter driver circuit coupled to, and operable to complementarily commutate, the first and second inverter switches, the inverter driver circuit including a DC supply input for receiving operating power for the inverter driver circuit;

a startup circuit coupled between the AC-to-DC converter and the DC supply input of the inverter driver circuit, the startup circuit being operable to provide power for initiating operation of the inverter driver circuit; and

a bootstrap circuit coupled between the first output terminal and the DC supply input of the inverter driver circuit, the bootstrap circuit being operable to provide steady-state operating power to the inverter driver circuit;

an output circuit comprising:

a direct current blocking capacitor coupled between the inverter output terminal and a first junction;

a first resonant inductor coupled between the first junction and the first output wire;

a second resonant inductor coupled between the first junction and the fifth output wire;

a first resonant capacitor coupled between the second and third output wires; and

a second resonant capacitor coupled between the sixth and seventh output wires; and

an inverter protection circuit, comprising:

a high voltage detection circuit having a first high voltage detect input coupled to the second output wire, a second high voltage detect input coupled to the sixth output wire, a ground connection coupled to the circuit ground node, and a high voltage detect output;

a no-load detection circuit having a no-load detect input coupled to the fourth output wire, a bootstrap detect input coupled to the bootstrap circuit, a no-load detect output coupled to the high voltage detect output, and a ground connection coupled to the circuit ground node;

a latch circuit having a latch input coupled to the no-load detect output, a latch output coupled to the DC supply input of the inverter driver circuit, and a ground connection coupled to the circuit ground node; and

wherein the inverter protection circuit is operable to:

(a) terminate operation of the inverter driver circuit by coupling the DC supply input of the inverter driver circuit to the circuit ground node in response to at least one of: (i) removal of all of the gas discharge lamps; (ii) failure of at least one of the gas discharge lamps to conduct current in a substantially normal fashion; and (iii) all of the gas discharge lamps each having at least one open filament; and

(b) allow continued operation of the inverter driver circuit, as long as: (i) at least one of the lamps is operating in a substantially normal fashion and with both of its filaments intact; and (ii) each of the failed lamps has at least one open filament.

15. The electronic ballast of claim **14**, wherein:

the inverter protection circuit is operable, in response to the voltage at the high voltage detect input being greater than a predetermined overvoltage threshold, to shut down the inverter driver circuit by coupling the DC supply input to the circuit ground node; and

the voltage at the high voltage detect input exceeds the predetermined overvoltage threshold in response to at least one of the lamps: (i) failing to conduct current in a substantially normal fashion; and (ii) having both of its filaments intact.

16. The electronic ballast of claim **15**, wherein:

the inverter protection circuit is operable, in response to the current flowing into the no-load detect input being less than a predetermined no-load threshold, to shut down the inverter driver circuit by coupling the DC supply input to the circuit ground node; and

the current flowing into the no-load detect input falls below the predetermined no-load threshold in response to at least one of:

(i) all of the lamps being removed; and

(ii) all of the lamps each having at least one open filament.

17. The electronic ballast of claim **14**, wherein the high voltage detection circuit comprises:

a first high voltage detect input coupled to the second output wire;

a second high voltage detect input coupled to the sixth output wire;

a high voltage detect output;

a first resistor coupled between the first high voltage detect input and a first node;

a second resistor coupled between the first node and the circuit ground node;

a diode having an anode coupled to the second node and a cathode coupled to a second node;

a capacitor coupled between the second node and the circuit ground node;

a third resistor coupled between the second node and the circuit ground node;

a zener diode having a cathode coupled to the second node and an anode coupled to the high voltage detect output; and

a fourth resistor coupled between the second high voltage detect input and the first node.

18. The electronic ballast of claim **14**, wherein the no-load detection circuit comprises:

a first resistor coupled between the no-load detect input and the circuit ground node;

a first diode having a cathode coupled to the no-load detect input and an anode coupled to the circuit ground node;

a second diode having an anode coupled to the no-load detect input and a cathode coupled to a first node;

a first capacitor coupled between the first node and the circuit ground node;

an electronic switch having a base lead, a collector lead, and an emitter lead, the emitter lead being coupled to the circuit ground node;

a second resistor coupled between the first node and the base lead of the electronic switch;

a third resistor coupled between the base lead of the electronic switch and the circuit ground node;

a third diode having an anode coupled to the bootstrap detect input and a cathode coupled to a second node;

a second capacitor coupled between the second node and the circuit ground node;

a fourth resistor coupled between the second node and the collector lead of the electronic switch; and

a fourth diode having an anode coupled to the collector lead of the electronic switch and a cathode coupled to the no-load detect output.

19. The electronic ballast of claim **14**, wherein the latch circuit comprises:

a first electronic switch having a base lead coupled to the latch input, an emitter lead coupled to the circuit ground node, and a collector lead;

a second electronic switch having a base lead, a collector lead, and an emitter lead, the emitter lead being coupled to the latch output;

a third electronic switch having a gate lead, a drain lead, and a source lead, the source lead being coupled to the circuit ground node;

a capacitor coupled between the latch input and the circuit ground node;

a first resistor coupled between the latch input and the circuit ground node;

a second resistor coupled between the latch input and the collector lead of the second electronic switch;

a third resistor coupled between the collector lead of the second electronic switch and the gate lead of the third electronic switch;

a fourth resistor coupled between the collector lead of the first electronic switch and the base lead of the second electronic switch;

a fifth resistor coupled between the latch output and the base lead of the second electronic switch; and

a sixth resistor coupled between the latch output and the drain lead of the third electronic switch.

20. The electronic ballast of claim **14**, wherein the bootstrap circuit comprises:

a capacitor coupled between the inverter output terminal and a first node, the first node being coupled to the bootstrap detect input of the no-load detection circuit;

a zener diode having a cathode coupled to the first node and an anode coupled to the circuit ground node;

a diode having an anode and a cathode, the anode being coupled to the first node; and

a resistor coupled between the cathode of the diode and the DC supply input of the inverter driver circuit.

21. The electronic ballast of claim **14**, wherein:

the AC-to-DC converter further comprises a rectifier circuit operable to receive the source of alternating current and to provide a rectified voltage between a pair of rectifier circuit output terminals; and

the startup circuit comprises:

a resistor coupled between the DC supply input of the inverter driver circuit and one of the output terminals of the rectifier circuit; and

a capacitor coupled between the DC supply input and the circuit ground node.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,869,935
DATED : February 9, 1999
INVENTOR(S) : Sodhi

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 9, claim 7, line 56 - 57 reads "an anode coupled to the circuit around node;" should be –an anode coupled to the circuit ground node; --.

Signed and Sealed this

Thirty-first Day of August, 1999

Attest:

Q. TODD DICKINSON

Attesting Officer

Acting Commissioner of Patents and Trademarks